Transverse polarization distributions

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I present a brief update on the transverse polarization distributions, focusing on model calculations and phenomenological perspectives.

1. Introduction

The transverse polarization (or transversity) distributions $\Delta_T q(x)$, introduced 20 years ago by Ralston and Soper [1] and studied in more detail in the last decade [2], are one of the three sets of leading-twist quark and antiquark distribution functions – the other two are the momentum distributions $q(x)$ and the helicity distributions $\Delta q(x)$. (Note that $\Delta_T q$ is often called h_1).

Formally $\Delta_T q$ is given by

$$\Delta_T q(x) = \frac{1}{\sqrt{2}P^+} \int \frac{d\alpha}{2\pi} \, e^{i\alpha x} \langle PS|\psi_+^\dagger(0)\gamma_\perp\gamma_5\psi_+(\alpha n)|PS\rangle \,, \tag{1}$$

where P and S are the momentum and the spin of the proton, respectively, n is a null vector such that $n \cdot P = 1$, and $\psi_+ = \frac{1}{2}\gamma^-\gamma^+\psi$. The antiquark distributions are obtained from (1) by exchanging ψ with $\psi^\dagger$.

Inserting a complete set of intermediate states $\{|X\rangle\}$ and using the Pauli–Lubanski projectors $\mathcal{P}_\perp^{\uparrow\downarrow} = \frac{1}{2}(1 \pm \gamma_\perp\gamma_5)$ one gets

$$\Delta_T q(x) = \frac{1}{\sqrt{2}} \sum_X \{|\langle PS|\mathcal{P}_\perp^\uparrow\psi_+(0)|X\rangle|^2 - |\langle PS|\mathcal{P}_\perp^\downarrow\psi_+(0)|X\rangle|^2\} \, \delta[(1-x)P^+ - p_X^+] \,. \tag{2}$$

which clearly shows the probabilistic meaning of $\Delta_T q$ in the transverse polarization basis: $\Delta_T q(x)$ is the number density of quarks with momentum fraction x and transverse polarization $\uparrow$ minus the number density of quarks with the same momentum and transverse polarization $\downarrow$, in a transversely polarized hadron. In the helicity basis $\Delta_T q$ is non diagonal and hence has no probabilistic interpretation.

Being a chirally odd distribution, $\Delta_T q$ is not measurable in deep inelastic scattering. This makes it quite an elusive quantity. At present we have no experimental information on it. That is why model calculations and other nonperturbative studies are particularly useful.

2. Models

The transverse polarization distributions have been calculated in a large number of models: *i)* bag model [3–5], *ii)* chromodielectric model [6], *iii)* chiral quark soliton and NJL model [7,8], *iv)* light-cone models [9,10], *v)* spectator model [11,12].

Many of these calculations show that, at small Q^2 ($\lesssim 0.5$ GeV^2), $\Delta_T q$ is not very different from Δq, at least for $x \gtrsim 0.1$. At low x the situation is more controversial: some models [7,10] predict a sensible difference between the two distributions. A definite conclusion cannot be drawn since the various models are valid at different scales and it is known that the QCD evolution induces a difference between $\Delta_T q$ and Δq which is relevant especially at low x [13].

As for the tensor charges

$$\delta q = \int_0^1 \mathrm{d}x \, [\Delta_T q(x) - \Delta_T \bar{q}(x)] \,, \tag{3}$$

in addition to the predictions of the models listed above, there are other nonperturbative estimates: by QCD sum rule methods [14], and by lattice QCD [15].

A rough (and personal) average of all model results is

$$\delta u \sim 1.0 \pm 0.2 \,, \quad \delta d \sim -0.3 \pm 0.1 \,, \quad \text{at } Q^2 \sim 2\,\mathrm{GeV}^2$$

where the error does not account for the intrinsic uncertainty of each model, but represents only the range spanned by the various results. For comparison, the lattice finding [15] is

$$\delta u = 0.84 \,, \quad \delta d = -0.23 \,, \quad \text{at } Q^2 \sim 2\,\mathrm{GeV}^2 \,.$$

Note that δu and δd are, in absolute value, only slightly smaller than the nonrelativistic expectations ($\delta u_{NR} = 4/3$, $\delta d_{NR} = -1/3$).

3. Possible measurements

As already mentioned, the transverse polarization distributions cannot be measured in inclusive DIS. To extract $\Delta_T q$ one needs either two hadrons in the initial state (hadron-hadron collisions), or one hadron in the initial state and one in the final state (semiinclusive deep inelastic scattering).

The measurement of $\Delta_T q$ in proton–proton collisions is part of the physics program of the experiments at RHIC [16] and of the proposed HERA-$\vec{N}$ project [17].

Among the possible pp initiated processes one can make a selection choosing those which are expected to yield the largest spin asymmetry. Since there is no gluon transversity distribution [2], all processes dominated at the partonic level by qg or gg scattering produce a very small transverse asymmetry [18]. Hence the most promising reaction is Drell-Yan lepton pair production with two transversely polarized beams. The relevant observable is the double–spin transverse asymmetry

$$A_{TT} = \frac{d\sigma_{\uparrow\uparrow} - d\sigma_{\uparrow\downarrow}}{d\sigma_{\uparrow\uparrow} + d\sigma_{\uparrow\downarrow}} \,, \tag{4}$$

which depends on the product (A and B are the two protons)

$$\Delta_T q(x_A) \, \Delta_T q(x_B) \,. \tag{5}$$

The Drell-Yan A_{TT} has been calculated at leading order [6,19] and next-to-leading order [20]. In [6,19] $\Delta_T q = \Delta q$ was assumed at a very low scale (the input μ^2 of the GRV distributions). The authors of [20], instead, set $|\Delta_T q| = 2\,(q + \Delta q)$ at the GRV scale, assuming the saturation of Soffer's inequality. This yields the maximal value for A_{TT}. Summarizing the results of these calculations we can say that at RHIC energies ($\sqrt{s} > 100$ GeV) one expects for the double-spin asymmetry, integrated over the invariant mass M^2 of the dileptons

$$A_{TT} \sim (1-2)\%\,, \quad \text{at most}\,. \tag{6}$$

It is quite interesting to note that, as $\sqrt{s}$ gets lower, the asymmetry tends to increase, as it was first pointed out in [6,19]. Thus at the HERA-$\vec{N}$ energies ($\sqrt{s} = 40$ GeV) A_{TT} can reach a value of $\sim (3-4)\%$, which should be measurable within the expected statistical errors for that experiment [20].

Let us turn now to semiinclusive DIS on a transversely polarized proton. There are three candidate reactions for determining $\Delta_T q$ at leading twist.

Detecting a transversely polarized hadron $\vec{h}$ (e.g., a Λ) in the final state,

$$e\,\vec{p} \to e\,\vec{h}\,X\,, \tag{7}$$

one measures the product

$$\Delta_T q(x)\,H_1^q(z)\,, \tag{8}$$

where H_1^q is a chirally odd leading-twist fragmentation function. In principle there is no reason why H_1 should be much smaller than the unpolarized fragmentation function D_1. The model calculation of [11] gives for instance $H_1^u/D_1^u \sim 0.5$ and $H_1^d/D_1^d \sim -0.2$.

The second relevant reaction is semiinclusive DIS with an unpolarized final hadron

$$e\,\vec{p} \to e\,h\,X\,. \tag{9}$$

In this case $\Delta_T q$ might appear as a consequence of the Collins effect [21] (a T-odd contribution arising from final state interactions). Here one measures

$$\Delta_T q(x)\,H_1^{\perp q}(z)\,, \tag{10}$$

where $H_1^{\perp q}$ is a T-odd leading-twist fragmentation function. The estimate of $H_1^{\perp q}$ presented in [22] and based on the analysis of pp reactions shows that this quantity is non negligible only at high z.

A third way to extract $\Delta_T q$ from semiinclusive DIS has been explored in [23]. The idea is to study the process

$$e\,\vec{p} \to e\,h_1\,h_2\,X \tag{11}$$

where h_1, h_2 are two mesons in a correlated state which is the superposition of two resonances h, h'

$$|h_1\,h_2\rangle = \mathrm{e}^{i\delta}\,|h\rangle + \mathrm{e}^{i\delta'}\,|h'\rangle\,. \tag{12}$$

For instance, $h_1, h_2 = \pi^+, \pi^-$ and $h, h' = \sigma, \rho$. In this reaction one measures

$$\sin\delta\,\sin\delta'\,\sin(\delta - \delta')\,\Delta_T q(x)\,I_q(z) \tag{13}$$

where $I_q(z)$ is the hh' interference fragmentation function. Nothing is known at present about this quantity.

From this sketchy presentation of the phenomenological perspectives it should be clear that, whereas the Drell-Yan process allows to determine $\Delta_T q$ in a clean way, semiinclusive DIS is characterized by the presence of fragmentation functions which are little known and, in some cases, are expected to be rather small.

REFERENCES

1. J.P. Ralston and D.E. Soper, Nucl. Phys. B152 (1979) 109.
2. X. Artru and M. Mekhfi, Z. Phys. C45 (1990) 669. R.L. Jaffe and X. Ji, Phys. Rev. Lett. 67 (1991) 552; Nucl. Phys. B375 (1992) 527; Phys. Rev. Lett. 71 (1993) 2547. J.L. Cortes, B. Pire and J.P. Ralston, Z. Phys. C55 (1992) 409.
3. R.L. Jaffe and X. Ji, in Ref. 2.
4. M. Stratmann, Z. Phys. C60 (1993) 763.
5. S. Scopetta and V. Vento, Phys. Lett. B424 (1998) 25.
6. V. Barone, T. Calarco and A. Drago, Phys. Lett. B390 (1997) 287.
7. H.-C. Kim, M.V. Polyakov and K. Goeke, Phys. Lett. B387 (1996) 577. P.V. Pobylitsa and M.V. Polyakov, Phys. Lett. B389 (1996) 350.
8. L. Gamberg, H. Reinhardt and H. Weigel, Phys. Rev. D58 (1998) 054014.
9. B.-Q. Ma, I. Schmidt and J. Soffer, Phys. Lett. B441 (1998) 461.
10. F. Cano, P. Faccioli and M. Traini, `hep-ph/9902345`.
11. R. Jakob, P.J. Mulders and J. Rodrigues, Nucl. Phys. A626 (1997) 937.
12. K. Suzuki and T. Shigetani, Nucl. Phys. A626 (1997) 886.
13. V. Barone, Phys. Lett. B409 (1997) 499.
14. H. He and X. Ji, Phys. Rev. D52 (1995) 2960; Phys. Rev. D54 (1996) 6897.
15. S. Aoki et al., Phys. Rev. D56 (1997) 433.
16. See, for instance, G. Bunce et al. , Part. World 3 (1992) 1.
17. M. Anselmino et al., preprint `hep-ph/9608393`
18. X. Ji, Phys. Lett. B284 (1992) 137. R.L. Jaffe and N. Saito, Phys. Lett. B382 (1996) 165.
19. V. Barone, T. Calarco and A. Drago, Phys. Rev. D 56 (1997) 527.
20. O. Martin et al., preprint `hep-ph/9902250`.
21. J. Collins, Nucl. Phys. B396 (1993) 161. J.C. Collins, S.F. Heppelmann and G.A. Ladinsky, Nucl. Phys. B420 (1994) 565.
22. M. Anselmino, M. Boglione and F. Murgia, `hep-ph/9901442`. M. Boglione and P.J. Mulders, `hep-ph/9903354`.
23. R.L. Jaffe, X. Jin and J. Tang, Phys. Rev. Lett. 80 (1998) 1166.